Quantum Machine Learning

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Motivation

What is Quantum Computing?

- Quantum mechanics applied to computation

Why use Quantum Computing?

- Capable of managing extremely large data sets
- Inherently parallelized
- Thousandfold computation speed increase potential
- Advantages cross over into ML applications

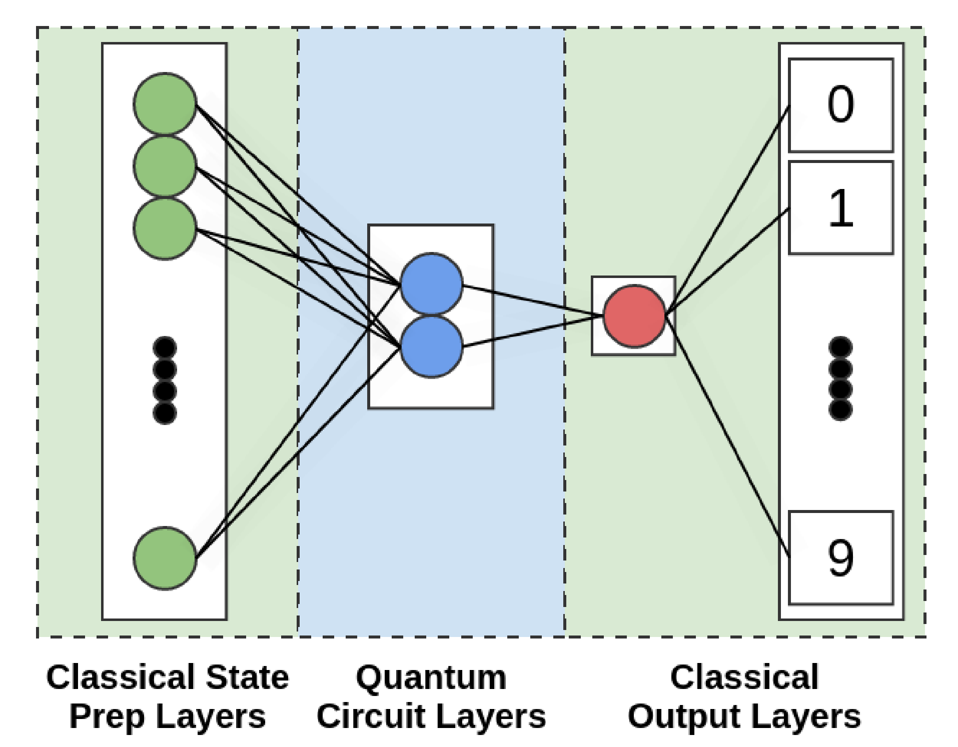
What are the Challenges?

- Execution time is a large barrier
- Increasing precision in terms of qubits adds complexity to several factors

Legacy IBM Quantum Computer

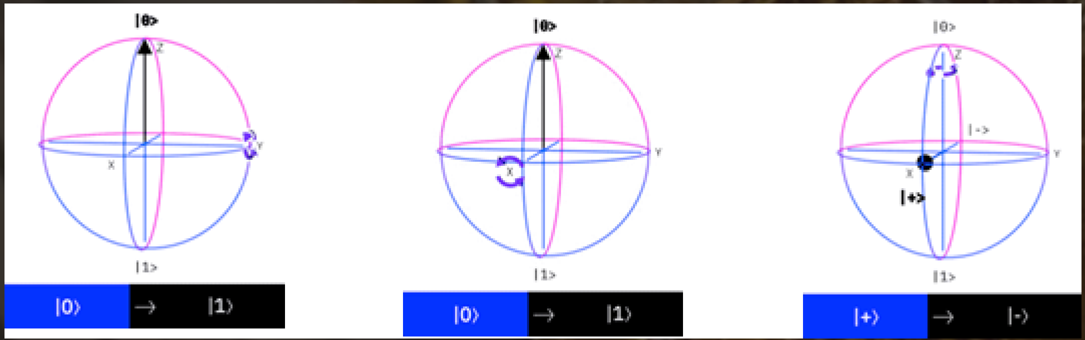
Hybrid Quantum-Classical Neural Networks

- Uses PyTorch and Qiskit, connected via TorchConnector module
- Classical component can be graphics processor unit (GPU) accelerated (Torch CUDA)

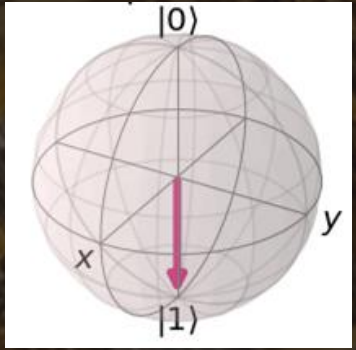


Quantum Hidden Layers

- Qubits perform gradient descent through rotations around a sphere
- Vector position represents state of the qubit (weights from training)



Rotation gate operations on qubits



Bloch Sphere Representation of a qubit

https://algassert.com/quirk#circuit={%22cols%22:[[%22Counting2%22],[%22Chance%22,%22Chance%22],[{%22id%22:%22Ryft%22,%22arg%22:%22pi%20t%22},{%22id%22:%22Ryft%22,%22arg%22:%22pi%20t%22}],[%22%E2%80%A2%22,%22X%22],[{%22id%22:%22Ryft%22,%22arg%22:%22pi%20t%22},{%22id%22:%22Ryft%22,%22arg%22:%22pi%20t%22}]]}

Quantum Simulators

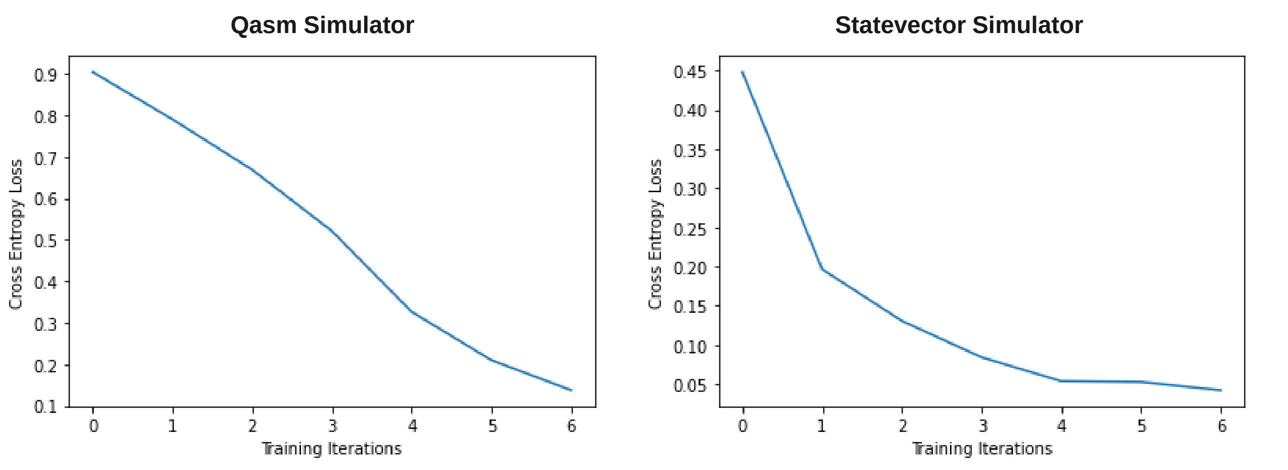
Simulator Options in Qiskit:

- Qasm - simulates noisy backend system
- Statevector - provides the state vector of the circuit
- Unitary - provides unitary matrix of circuit
- Pulse - simulates pulse schedules to execute directly on hardware channels

Simulator:	Qasm	Statevector
Runtime (min):	14.38	10.44
Accuracy (%):	96-99	99.4

System Specifications:
PopOS 20.10
Ryzen 9 4900HS
RTX 2060

2 Qubit QNN, 7s vs 1s on MNIST Dataset - Cost Reduction



Challenges

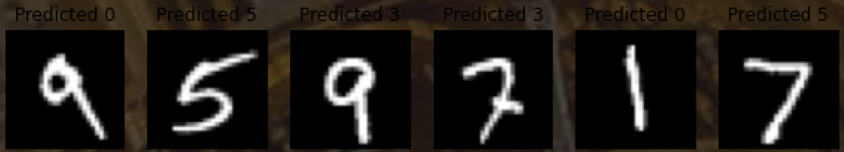
Accuracy

- Small number of qubits introduces resolution-related noise
- Experimentation suggests as qubit number increases, stability and reliability decrease

Time

- Most models require several hours to train
- Hybrid nature of QNNs make development difficult
- Have cut time down from ~12+ hours to around 45 minutes

Selection of test results from trained MNIST QNN model

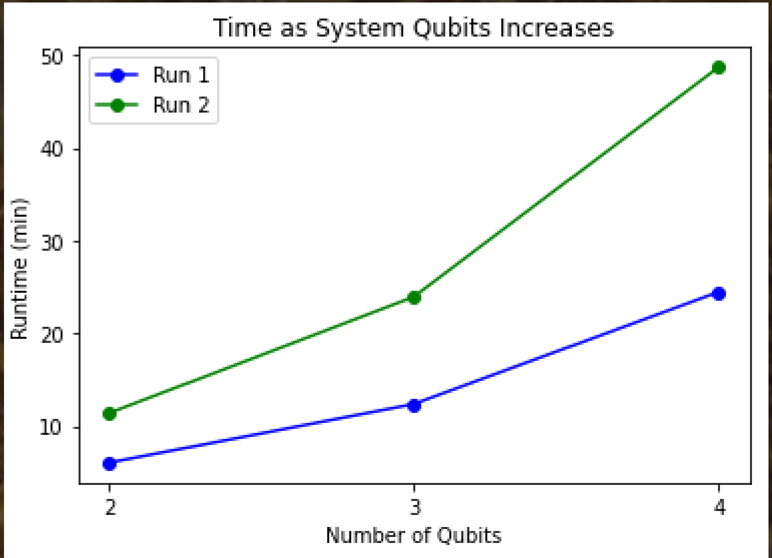


Accuracy and training time for MNIST QNN model

```
Starting epoch 0 for 2 qubits
Training [20.000000%]    Loss: 2.5762
Starting epoch 1 for 2 qubits
Training [40.000000%]    Loss: 2.3445
Starting epoch 2 for 2 qubits
Training [60.000000%]    Loss: 2.3263
Starting epoch 3 for 2 qubits
Training [80.000000%]    Loss: 2.3193
Starting epoch 4 for 2 qubits
Training [100.000000%]   Loss: 2.3160
Training runtime for two qubits is:  176.34958395560582  min
Performance on test data:
        Loss: 2.3158
        Accuracy: 11.3%
Evaluation time is:  0.259
```

Effects of Higher Qubit Numbers

- Increasing qubits in a simulated environment increases runtime as expected
- Results in simulation vary, but overall pattern is consistent



Future work

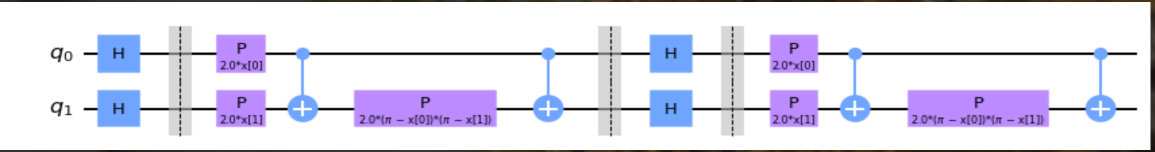
- Fixing issue with evaluation code
- Would like to try 5+ qubits and

Quantum Circuit Complexity Reference

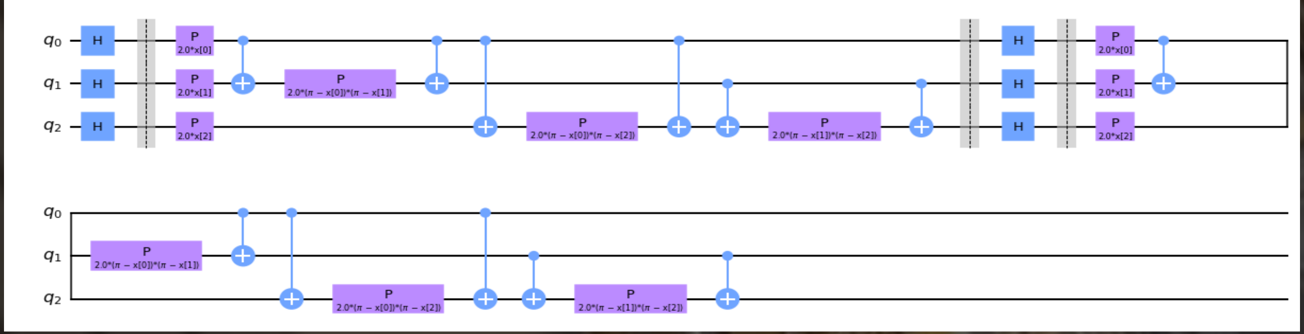
The quantum circuit:

- Provides abstracted representation of the quantum program logic
- Can increase number of qubits to increase resolution, comes at the cost of error (noise)
- Expected to be solved as technology matures

2 Qubit feature map



3 Qubit feature map



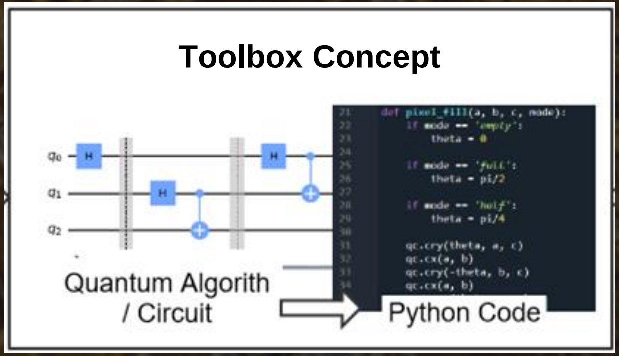
Concluding Remarks

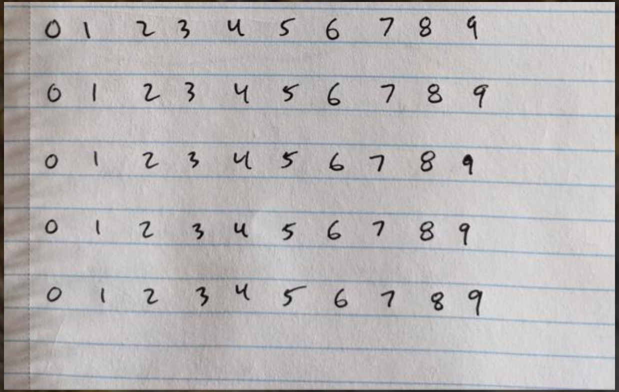
Results So Far

- Improved architecture for hybrid QNNs
- Demonstrated functionality on MNIST dataset
- Developed two separate frameworks for handling multi-class datasets on a hybrid network

Next Steps

- Continue work through independent study in the Fall semester. Will entail:
  - Model improvements
  - Circuit improvements
  - Expansion of models to real-world datasets
  - Tool comparison in regard to complexity of design, execution time, user-friendliness
- Develop handover documentation to pass on the research for future work
- Turn existing code into simple toolbox solutions





Sources

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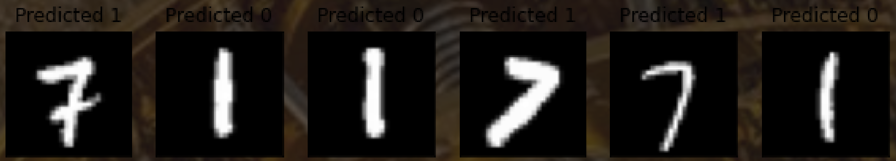
Results So Far (EXTRA)

Training on 2 digits

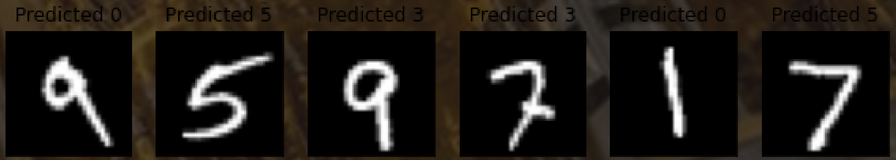
- ❑ High accuracy when comparing only two samples
- ❑ Operates well with simple 2 qubit computers and sims




```
Performance on test data:
        Loss: 0.0565
        Accuracy: 99.4%
Evaluation time is:  0.027743311723073323  min
```

Training on all 10 digits

- ❑ Lower accuracy and extremely long training time



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